

Onboard Detection of Thermal Anomalies for Europa Clipper

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1. Introduction

The *Europa Clipper* mission seeks to assess the habitability of Jupiter's moon Europa [6, 1]. *Europa Clipper*'s payload comprises nine instruments, including the Europa Thermal Emission Imaging System (E-THEMIS) for detecting thermal anomalies (e.g., hot spots) and the Mapping Imaging Spectrometer for Europa (MISE) for assessing composition. E-THEMIS can detect melting ice and other surface anomalies from 40,000 km above the surface. MISE covers the range 0.8–5.0 μm and can distinguish between water ice phases, organics, salts, etc. [2].

Europa Clipper will conduct ~ 45 flybys of Europa. The large Earth–Jupiter distance severely constrains the amount of data that can be downlinked from the spacecraft. To help maximize the scientifically valuable data returned by the mission, we are investigating approaches to perform basic data analysis onboard the spacecraft to identify the most relevant and valuable data to downlink with a higher priority.

Onboard science data analysis has been employed for Earth orbiters such as EO-1 to detect and prioritize biosignatures in Europa-analogue settings, such as biomediated sulfur deposits on glaciers [5]. The Mars Science Laboratory rover analyzes images as they are collected, then commands the ChemCam laser spectrometer to collect spectra of the most interesting rock

targets, without human intervention [4]. A previous study determined that the THEMIS instrument in Mars orbit could reliably detect thermal anomalies, aerosols, and ice features of interest [3].

Europa observations of high interest include those containing thermal and spectral anomalies that could signal the presence of hot spots, plumes, or deposits of organic materials at the surface. Any thermal anomalies detected in E-THEMIS data can also potentially inform prioritization of coincident MISE data during closer approach in the same flyby.

2. THEMIS Anomaly Detection

To develop and evaluate onboard thermal anomaly detection algorithms, we use data from analog instruments flown on previous missions. In particular, the THEMIS instrument on the Mars Odyssey spacecraft is a thermal imaging instrument and predecessor of the E-THEMIS instrument. We have applied an approach for onboard THEMIS anomaly detection [3] to THEMIS data observed since the original study in 2007. Our updated analysis encompasses 56,985 observations from the start of the mission through 2017 taken after midnight but before dawn local time between -60 and 60 degrees latitude.

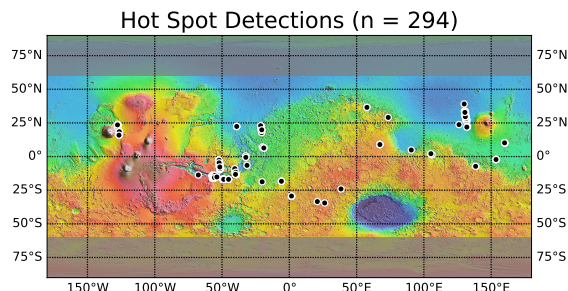


Figure 1: Hot spot detections (≥ 240 K) from 14 years of THEMIS Mars data. Base map is MOLA elevation.

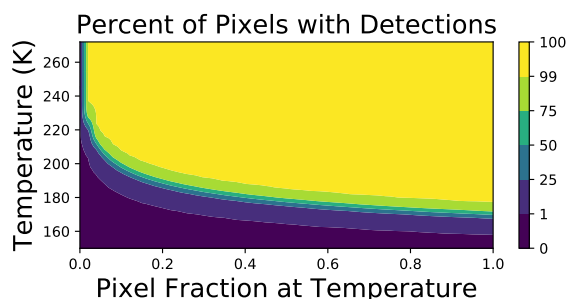


Figure 2: Characterizing the probability of detection across all pixels for injected thermal anomalies of various sizes and temperatures in NIMS observations at $\alpha = 0.05$ significance.

The detection algorithm converts digital numbers to temperatures, then flags pixels ≥ 240 K as anomalous. If an observation contains too many pixels exceeding this threshold, it is discarded. After filtering these poorly calibrated observations, only a small fraction of pixels exceed this threshold, and no pixel exceeded 248 K. Adjacent pixels exceeding the 240 K threshold are clustered together into single “detections,” shown in Figure 1.

The detected hot spots occur in regions with high thermal inertia (e.g., exposed outcrop) that remain relatively warm during the night. A similar detection algorithm onboard *Europa Clipper* could be used to find endogenic heat sources on Europa (employing a lower temperature threshold).

3. NIMS Anomaly Detection

Observations of Europa by the Galileo NIMS instrument (0.7–5.2 μm) provide a good analogue for future MISE observations. We injected synthetic thermal anomalies into real NIMS data, then assessed our ability to detect those anomalies.

First, we compute a blackbody spectrum as observed by NIMS for a given temperature and viewing geometry with the original observation. We linearly combine this spectrum with each pixel in the observation, proportional to the intended anomaly size (we assume no existing thermal anomalies). Next, to detect the presence of a thermal anomaly, we compare the radiances in the 5–5.2 μm range to the radiances in the 3.5–4.5 μm range using Welch’s t -test. Finally, we compute the fraction of pixels for which the anomalies are detected, with a Bonferroni correction to account for the multiple hypothesis tests across every pixel in an observation.

Figure 2 shows the detection rate across all pixels in 14ENSUCOMP01A as the anomaly temperature and size is varied. For example, an anomaly at 190 K that comprises 50% of the 1.6 km^2 pixel is detected over 80% of the time.

We have also run the detection algorithm on the original observation with no anomalies injected. There are several pixels in the 14ENSUCOMP01A observation that have relatively low p -values, though not low enough to be significant under the threshold used in the previous analysis. The radiance curves for these pixels increase after 5 μm , but it is difficult to determine whether the observed increase is evidence of a signal or due to noise. Nevertheless, these detections show that the algorithm identifies observations that merit further investigation.

4. Conclusion and Future Work

Our current results show that it is possible to use on-board methods to quickly flag data for high-priority downlink and investigation. Our next step is to investigate thermal anomaly detection algorithms using simulated data from the E-THEMIS instrument. We will use a Europa thermal model to simulate background temperatures, then inject synthetic thermal anomalies as above. We will also investigate the detection of spectral anomalies that indicate interesting minerals or deposits of organic materials on the surface.

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